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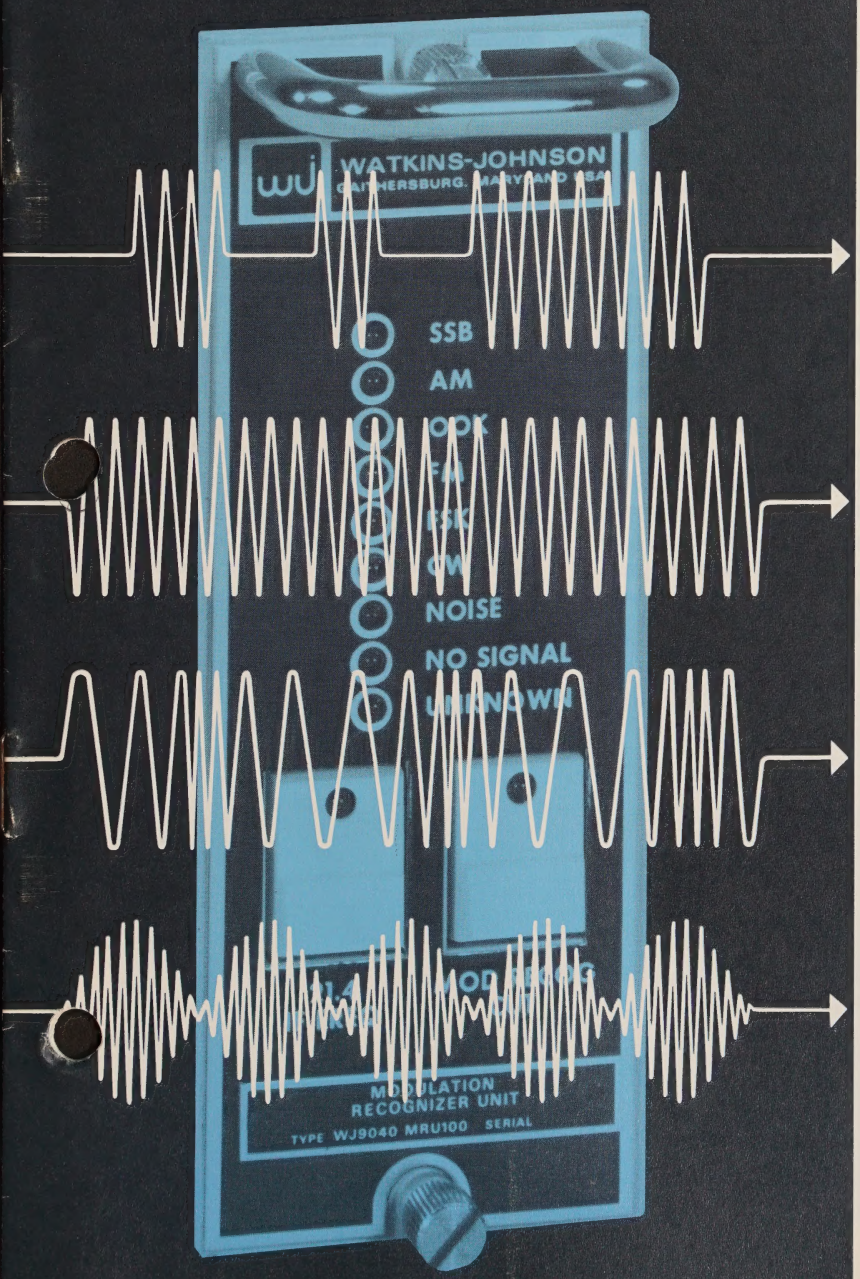
Modulation Recognition for Automated Surveillance Systems



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Tech-notes

A modulation recognizer is a device for automatic recognition of modulation type. Such a device provides an additional and highly important parameter for signal sorting. Potential applications of the device are described in this article, and approaches to development of such a device are touched upon. A technique developed at Watkins-Johnson is described in general terms. Its performance is reported, and means for improving performance using adaptive decision techniques are described.

Introduction

The foremost purpose of surveillance is threat recognition. This is accomplished by cataloging the signal characteristics of each emitter type which constitutes a threat or potential threat. Using such a catalog, threats (or potential threats) can later be identified when they are intercepted during surveillance. Characteristics used to classify signals are normally called signal-sorting parameters. One of the most important sorting parameters is modulation type. A device for accomplishing this function is called a modulation recognizer.

This article addresses potential applications for such a device and approaches to modulation recognition.

Definition of a Modulation Recognizer

A modulation recognizer automatically identifies the type of modulation, such as am (amplitude modulation), cw (continuous wave), fm (frequency modulation), fsk (frequency shift keying), etc., present on an incoming rf signal. It performs this function by analyzing the IF output of a typical communications receiver as illustrated in Figure 1.

Applications of a Modulation Recognizer

The primary use of a modulation recognizer is to enhance an automatic receiving system by providing an additional and highly important signal-sorting parameter; namely, modulation type. In such a system, information regarding modulation type may be combined with other signal parameters, such as frequency, direction of arrival, signal strength, etc., to produce appropriate control signals which cause certain functions to occur, including starting a recorder, alerting an operator, and halting the frequency-scan process.

As an example, Figure 2 is a block diagram illustrating an automatic receiving system. This system consists of a receiver, a modulation recognizer, a

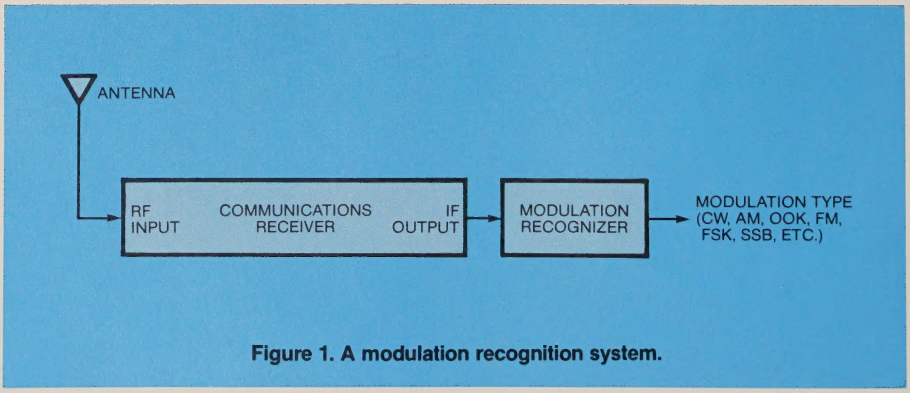

Figure 1. A modulation recognition system.

set of demodulators and recorders, and a system controller which is used to coordinate all the modules in the system. In a typical case, the receiver scans the rf spectrum. If the operator wants to record or to demodulate signals having certain combinations of modulation type and frequency, he can program the system controller accordingly. He can preprogram into the controller the frequencies of interest as well as the modulation types of interest at these frequencies.

As the receiver scans, the modulation recognizer continually and automatically recognizes the modulation type of the signal to which the receiver is tuned. The system controller constantly monitors this modulation information and the frequency information provided by the receiver. When the combination of the modulation type and frequency matches one of the combinations stored in the controller, the controller, as instructed by the program, might in this case cause the following sequences to occur: First, the frequency scanning halts, then an appropriate demodulator is switched in to begin demodulation. Finally, a recorder is turned on. The system may remain in this new state for either a prescribed period of time, or until the end of a conversation, before frequency scanning is resumed.

Another example of the application of the modulation recognizer includes a direction finder in the above receiving system. In this case, the operator may want to demodulate or to record a signal satisfying certain combinations of frequency, modulation type, and direction-of-arrival parameters. Again, the operator enters a set of combinations of frequency, modulation type, and direction-of-arrival into the controller. If he chooses to listen to a received signal having a particular combination of frequency, modulation type, and direction-of-arrival parameters, he can program the controller so that when that combination is detected, the controller will halt the frequency-scanning process, switch in

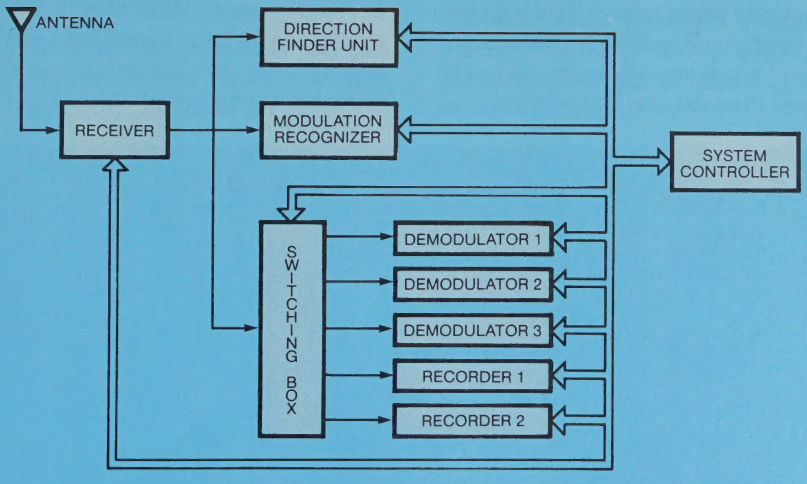

Figure 2. A typical automated receiving system.

an appropriate demodulator, and wait for the operator to manually resume the frequency-scanning process.

Approaches to Modulation Recognition

Several approaches to modulation recognition are possible. One incorporates a bank of demodulators as shown in Figure 3. Each demodulator in the bank is designed to demodulate only one of several types to be considered. By comparing the outputs of these demodulators, it is possible to identify the modulation type. Obviously, if an operator were present, he could tell which type is present by examining or listening to each of the demodulator outputs. But the use of an operator to perform the modulation type classification is not automatic and, therefore, does not fall under the domain of modulation recognition as defined herein. A modulation recognizer should be designed to identify the modulation type automatically. This requires a set of intelligent decision algorithms. A brief examination of the problem of generating the required algorithms using this method indicates that they would be highly complex and require considerably more computer storage than the method selected.

Another approach (Figure 4) to the modulation-recognition problem involves the use of spectral analysis by means of advanced digital signal-processing techniques, such as the Fast Fourier Transform (FFT). With this approach, the signal is first sampled and quantitized, then processed by either a special-purpose digital computer, or a general-purpose microcomputer. Processing entails the comparison of the signal's spectrum with spectra expected for each of the modulation types. Since the signal spectrum is a time-varying function of the modulating signal, some form of statistical comparison is necessary.

The approach developed at Watkins-Johnson involves a novel method, which is depicted in the block diagram of Figure 5. Here, the envelope amplitude and zero-crossing times of a received signal are sampled at a rate of about 100 samples/second. For each decision cycle, two-hundred pairs of samples are taken. These data points are processed in a microcomputer using a set of simple algorithms to determine modulation type. The algorithms perform statistical tests on the envelope and zero-crossing data, then apply the results to a decision algorithm based on the *concept of similarity* used in pattern-recognition theory. The

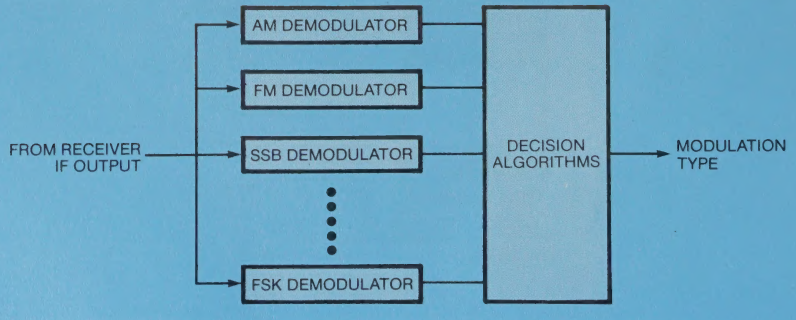

Figure 3. Modulation recognizer incorporating a bank of demodulators.

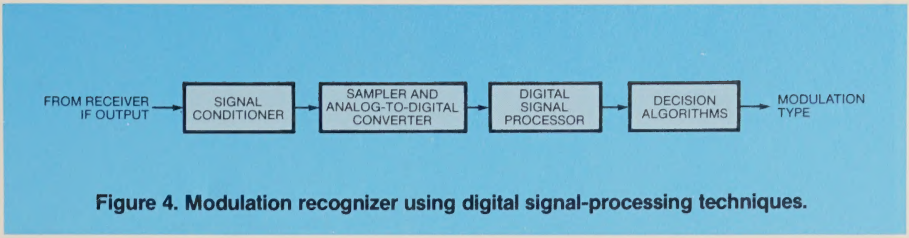

Figure 4. Modulation recognizer using digital signal-processing techniques.

algorithms are simple, and readily provide adequate confidence when the signal-to-noise ratio is reasonably high. For example, a signal-to-noise ratio of 20 dB yields a correct decision on am or fm with a probability that exceeds 0.99, with confidence of 96%.

Compared with other approaches considered, this method has the advantages of small size, light weight, low power consumption, and flexibility.

Figures 6 and 7 show the block diagrams of the modulation-recognition hardware which performs the following five primary functions: 1) Recovery of envelope and zero crossings. 2) Collection of envelope and zero-crossing samples. 3) Statistical computations. 4) Execution of decision algorithms. 5) Communication with the external controller.

The envelope sampler employs a conventional envelope detector, a sample-and-hold amplifier, and an analog-to-digital converter. The zero-crossing sampler consists of a carrier-tracking loop, a high-speed counter, and a pulse generator. During a sampling cycle, the rising edges of one period of the received carrier are used to latch the contents of the high-speed counter at the beginning and end of the period (see Figure 8). These two numbers are stored in the computer, where their difference is computed. This difference is a measure of the instantaneous period, or the inverse of the instantaneous frequency of the received signal at the sampling time.

A phase-locked loop is employed to recover the carrier, because in certain types of modulation the carrier may be severely suppressed. For example, the carrier is almost totally suppressed when the modulation depth on an am signal is more than 80% (Figure 9). Carrier recovery during suppressed portions of the signal is equivalent to receiving a signal when the signal-to-

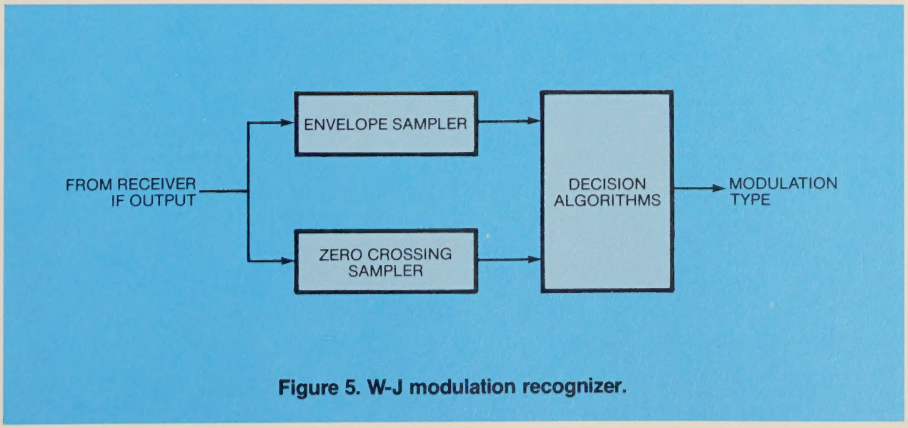

Figure 5. W-J modulation recognizer.

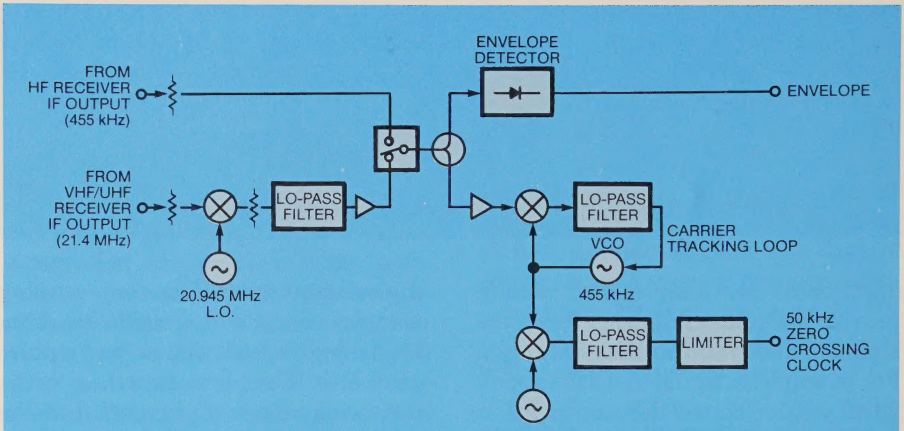

Figure 6. Modulation recognizer block diagram, analog portion.

noise ratio is very low. A phase-locked loop behaves like a bandpass-tracking filter. The narrower the closed loop bandwidth, the more received noise can be filtered out. The phase-locked loop can also be designed to possess some memory. Thus, when the input carrier becomes very small, or even absent, the phase-locked loop can still operate without losing lock for a short period of time. This flywheel behavior is very important in recovering the carrier of a signal whose amplitude modulation is close to or greater than 100%.

As can be seen from the block diagram in Figure 5, the hardware requirements for the W-J approach are simple. The only critical hardware circuits are an envelope detector/sampler and a zero-crossing sampler. These circuits were relatively easy to design.

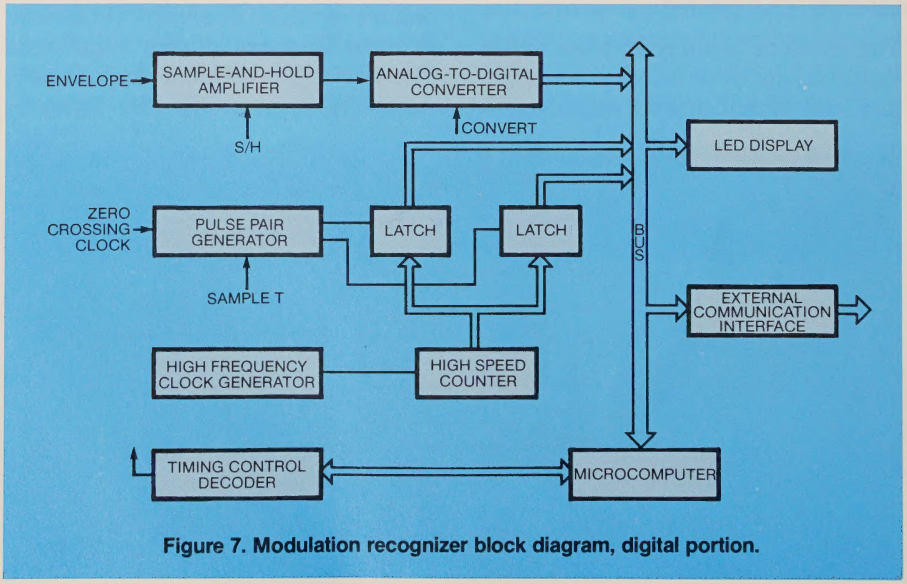

Figure 7. Modulation recognizer block diagram, digital portion.

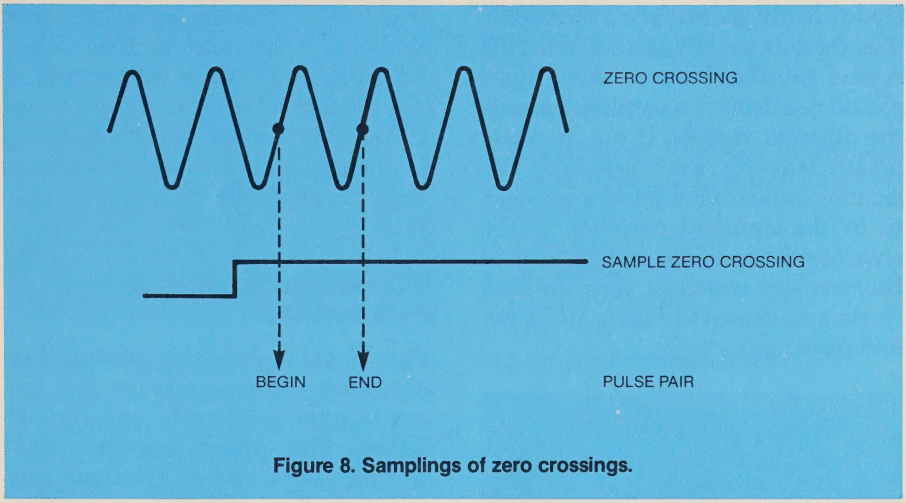

Figure 8. Samplings of zero crossings.

The bulk of the work in developing the modulation recognizer has gone into its software. A software-intensive modulation recognizer has the important advantage of being very versatile. A variety of software algorithms can be written to extract different parameters either singly or simultaneously. This software can reside in EPROM, which can easily be changed for different signal-acquisition applications.

Recognition Algorithm

The recognition algorithm used by the modulation recognizer is based on what is known as the "concept of similarity" in pattern-recognition theory. To use this algorithm, the key features that help to make each signal unique must be identified. For instance, the time between zero crossings of the carrier would help to identify an fm signal.

Once these features are determined, a sample feature set of all identified features must be collected for each signal of interest. The sample set for one signal is treated as a class of data. There is one class for each signal. After all the sample sets have been collected, the data is reduced by calculating the mean and standard deviation of each feature for a given class. These final results are saved to be used in the distance formula which follows.

If each feature above is treated as a separate axis in an n-dimensional space (for n features), and the collected

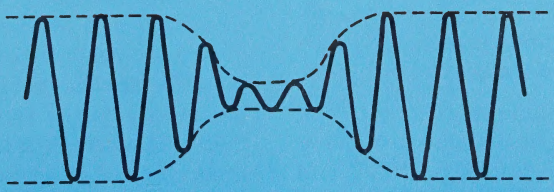

Figure 9. Signal with high percentage of am modulation.

feature data is plotted along these axes, then the data usually clusters about the means calculated above. Also, there should be a distinct separation between the different classes. If not, inappropriate features were selected. For example, when two features are chosen to be the standard deviation of the envelope of the signal and of the time between zero crossings, then the data clusters as shown in Figure 10 for am and fm signals.

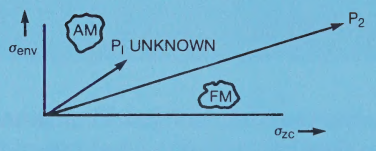

Figure 10. Clusters in feature space.

To classify an unknown signal, the same feature set is used as is used for the known signals. This set of data points is treated as an n-dimensional vector (for n features). The distance of this vector to each of the signal classes is:

$$DISSQ(c) = \left[\prod_{f=1}^{n} SD(f,c)\right]^{2/n} \times \left\{\sum_{f=1}^{n}\left[\frac{P(f) - M(f,c)}{SD(f,c)}\right]^2\right\}$$

where, f is the feature, c is the class, P(f) is a feature of the unknown signal, M(f,c) and SD(f,c) are the mean and standard deviation, respectively, and n is the number of features.

The type of signal represented by the unknown must be the class to which it is the closest, i.e., smallest DISSQ. It is more difficult to determine which types it is not. If even the smallest DISSQ is so great that it falls far out of range of the clusters, then the signal should be thrown out as indeterminate. Thus, where vector P_1 would be classified as am, since it is closer to that class, vector P_2 would be thrown out, even though it is closer to fm, because its distance from the fm cluster is too great.

Modulation-Recognizer Performance

The Watkins-Johnson modulation recognizer will recognize cw, am, fm, ssb (single sideband), ook (on-off keying), bfsk (binary frequency shift keying), and noise. Because our approach to modulation recognition utilizes only envelope and zero-crossing samples, and because these samples can be corrupted by random noise, the performance of the modulation recognizer is mainly a function of the signal-to-noise ratio at the output of the receiver which preceeds it. This is so because noise tends to spread the data clusters in the feature space. In the ideal noiseless situation, the data clusters shrink to distinct points, each of which represents a modulation type. As the signal-to-noise ratio decreases, these clusters expand until they eventually overlap. Other factors also contribute to the distortion of the envelope and the zero crossings. These include nonlinearities in the receiver front end and multipath effects. The effects of these latter factors on the probability of correct recognition have not been investigated.

The performance of the modulation recognizer can be characterized by a group of recognition probability matrices (see Figure 11). Each entry in the matrix is the recognition probability, Pij, where Pij is the probability of occurrence of an event, Xij, in which type i modulation is recognized as being type j. A complete 2-D matrix describes the modulation-recognizer performance

$$[P_{ij}] = \begin{bmatrix} P_{11} & P_{12} & P_{13} & \cdots & P_{1n} \\ P_{21} & P_{22} & P_{23} & \cdots & P_{2n} \\ P_{31} & P_{32} & P_{33} & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & & \vdots \\ P_{m1} & P_{m2} & P_{m3} & \cdots & P_{mn} \end{bmatrix}$$

Figure 11. Recognition probability matrix.

at a given signal-to-noise ratio. Since the modulation-recognizer performance is a function of signal-to-noise ratio, a family of recognition probability matrices is needed to characterize its behavior more completely. The elements on the principal diagonal of a matrix are probabilities of correct modulation recognition. The closer these numbers are to 1, the better the performance.

Conclusion

The approach developed at W-J and described herein has the following advantages:

a. Viable performance
b. Simplicity
c. Highly versatile
d. Low cost
e. Low power consumption (<6W)

Figure 12 shows a photograph of a prototype modulation recognizer.

Acknowledgement

Another significant contributor to this project is Watkins-Johnson engineer Pam Greene.

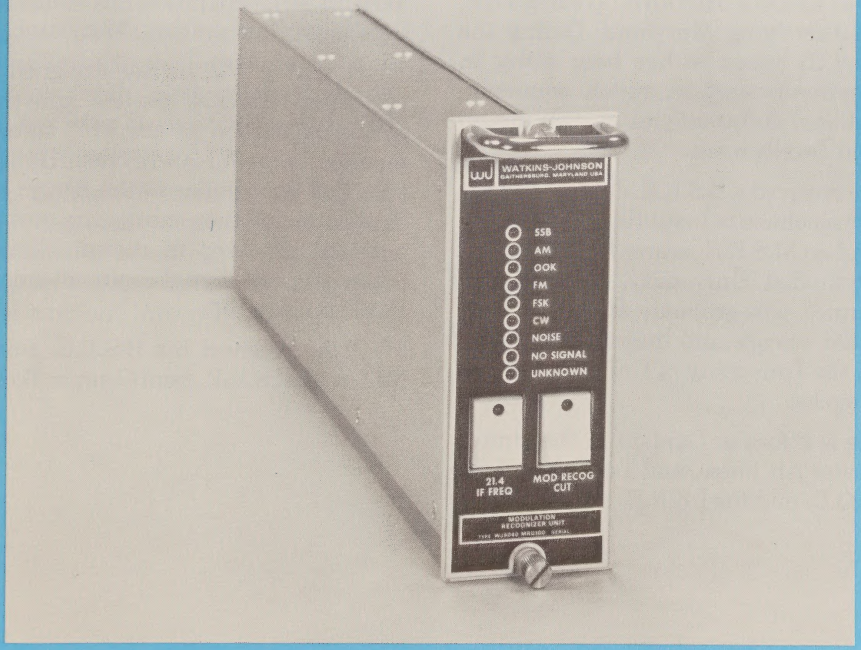

Figure 12. Photograph of prototype modulation recognizer.

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Jerry L. Perry is a Staff Scientist at Watkins-Johnson Company, Gaithersburg, Maryland. During the past 31 years he has been active in electronic warfare, radar, communications, and multiplex system design and development.

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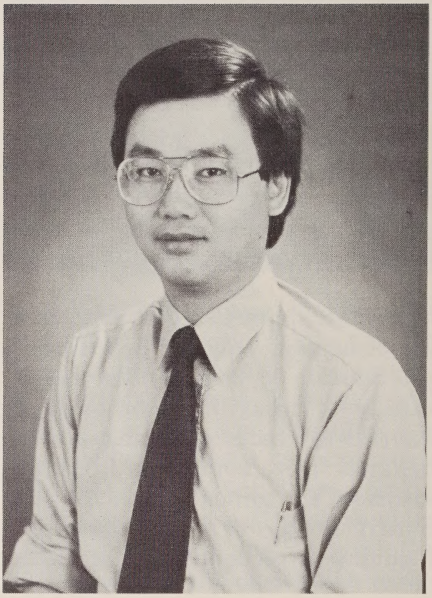
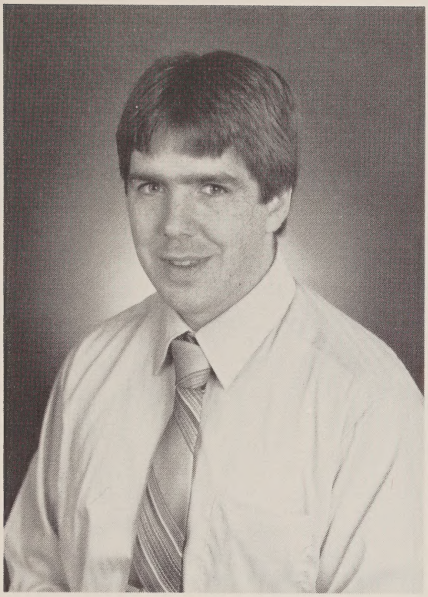


Jong-Kie Tjho

Mr. Jong-Kie Tjho is a Member of the Technical Staff, Watkins-Johnson Company, Gaithersburg, Maryland.

Since joining W-J, he has designed a frequency-reference module and the rf/analog portion of the FFT signal monitor for the WJ-9040 system. He is a principal contributor to the design of the W-J modulation recognizer, and is actively involved in digital signal processing and digital communication IR&D projects.

Mr. Tjho received his B.S.E.E. from MIT, and M.S.E.E. from Georgia Tech.



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Mr. Callaghan has worked as a design engineer and project engineer on programs dealing with receiver digital control and digital signal processing. In addition to the hardware/software designs for the modulation recognizer, he has also been involved with FFT signal monitors.

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